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DOI: https://doi.org/10.1111/clr.13020

Originally published at:
Sancho-Puchades, M; Crameri, D; Özcan, M; Sailer, I; Jung, R E; Hämmerle, C H F; Thoma, D S (2017). The influence of the emergence profile on the amount of undetected cement excess after delivery of cement-retained implant reconstructions. Clinical Oral Implants Research, 28(12):1515-1522.
DOI: https://doi.org/10.1111/clr.13020

The influence of the emergence profile on the amount of undetected cement excess after delivery of cement-retained implant reconstructions

Sancho-Puchades M*, Crameri D*, Özcan M, Sailer I, Jung RE, Hämmerle CHF, Thoma DS

Author & affiliation

Author 1,2,3,5,6,7: Clinic of Fixed and Removable Prosthodontics and Dental Material Science, Center of Dental Medicine, University of Zurich, Zurich, Switzerland

Author 4: Division for Fixed Prosthodontics and Biomaterials, University of Geneva, Geneva, Switzerland.

*These authors contributed equally to the study

Key words: dental cements, cementation, dental implants, peri-implantitis

Running title: Emergence profile and cement excess

Number of figures: 7

Number of tables: 5

Word count: 3123

Address for correspondence:

PD Dr. Daniel S. Thoma

Clinic of Fixed and Removable Prosthodontics and

Dental Material Science

Center of Dental Medicine, University of Zurich

Plattenstrasse 11

CH-8032 Zurich, Switzerland

Phone: +41 44 634 32 60

Fax: +41 44 634 43 05

e-mail: daniel.thoma@zzm.uzh.ch

Abstract

Objective: To test whether or not one out of two emergence profile designs (concave or convex) is superior to the other in terms of remaining cement following cementation of reconstructions on individualized abutments and careful cement removal.

Materials and methods: A central incisor with a single implant-supported reconstruction was selected as a model. Six types of abutments (n=10) with two different emergence profile designs (concave (CC) and convex (CV)) and 3 crown-abutment margin depths (epimucosal, 1.5 mm submucosal, 3 mm submucosal) were fabricated through a CAD/CAM procedure. Lithium disilicate reinforced ceramic crowns were cemented with chemically-polymerized resin cement. A blinded investigator attempted to remove all cement excess. Thereafter, the entire reconstruction was unscrewed and analyzed for the overall amount and the depth of cement excess. Kruskal-Wallis and Mann-Whitney tests were used to investigate differences between groups. When more than two groups where compared between each other a Bonferroni correction of the p value was performed.

Results: Concave abutments presented significantly more cement remnants than CV abutments when the entire abutment area of the epimucosal margin groups was evaluated (CC0mm: mean 2.31 mm^2 (SD 0.99) vs. CV0mm: mean 1.57 mm^2 (SD 0.55); $p=0.043$). A statistically significant increase of remnants was detected when the crown-abutment margin was located more submucosally for every abutment studied (0mm vs. 1.5mm: $p<0.000$, 0mm vs 3mm: $p<0.000$, 1.5mm vs. 3mm: $p<0.000$). The buccal quadrant demonstrated the least, whereas the oral and interdental quadrants showed the greatest amount of cement excess.

Conclusions: Concave emergence profile abutments and deep crown-abutment margin positions increased the risk of cement excess. Oral and interdental areas are more prone to cement remnants than other surface areas.

Introduction

The connection between dental implants and prosthetic reconstructions can be obtained by different means. Implant reconstructions can be either screw-retained or cemented. Both types of fixation render clinically successful long-term outcomes; the five-year survival rates for single-crown screw-retained reconstructions is estimated to be 89.3% (95% CI: 64.9-97.1%), whereas cemented reconstructions demonstrate survival rates of 96.5% (95% CI: 94.8-97.7%), without reaching statistically significant differences (Sailer et al. 2012). According to recent systematic reviews (Sherif et al. 2014; Wittneben et al. 2014), each approach has its own advantages and disadvantages. This fact is reflected by their technical and biological complication rates observed during the 5-year follow-up period. The cumulative incidence of technical complications for single-crown screw-retained reconstructions was 24.4%, whereas for cemented reconstructions the rate was of 11.9%. Moreover, biologic complications, such as marginal bone loss > 2 mm, were more frequently associated with cemented than with screw-retained reconstructions (2.8% vs 0%).

Cemented reconstructions offer advantages such as ease of fabrication, reduced costs, increased framework passivity and improved esthetics due to the absence of screw access hole in the occlusal surface of the crown (Hebel & Gajjar 1997). Nevertheless, the scientific literature highlights an increased risk of experiencing major biological complications with this type of fixation (Capelli et al. 2010; Chambers et al. 2009; Gapski et al. 2008; Linkevicius et al. 2013a; Sailer et al. 2012; Wilson 2009). These biological complications are related to the assumption that cement excess removal after cementation is difficult and often remnants remain on the implant surface and the surrounding tissues. Cement remains act as “artificial calculus” and might favor peri-implant disease and progressive marginal bone loss (Renvert & Quirynen 2015; Wilson 2009).

In an in vitro study (Agar et al. 1997), cement excess removal around implant crowns was evaluated with crown margins placed at various levels below an artificial mucosal margin. Cement remnants where always present after the removal procedures, independent of the operators experience or instruments used. However, other factors, such as the type of cement and the vertical position of the crown/abutment interface, appeared to be influential. These outcomes are supported by a series of in vitro and in vivo studies demonstrating that the depth of the crown/abutment interface negatively influenced the ability to precisely remove cement remnants (Linkevicius et al. 2013a; Linkevicius et al. 2013b; Linkevicius et al. 2011). Another potential influencing factor could be the shape of the abutment's emergence profile. It is speculated that abutments with a concave emergence profile could negatively influence the removal of excess cement compared to abutments with a convex profile.

The aim of the present in vitro investigation was therefore to test whether or not one out of two emergence profile designs (concave or convex) is superior to the other in terms of remaining cement following cementation of reconstructions on individualized abutments and careful cement removal.

Materials and methods

Study design

The in vitro investigation compared two groups of customized abutment designs: a concave (CC) and a convex (CV) profile. The main groups were assigned to 3 subgroups according to the depth of the crown-abutment margin: epimucosal (0mm), 1.5 mm submucosal (1.5mm) and 3 mm submucosal (3mm). Ten units of each abutment modality were fabricated (Figure 1).

Abutments and crowns design and fabrication

An anonymous clinical case comprising a single unit implant-supported restoration on a central maxillary incisor was selected from the pool of patients treated at the Clinic for Fixed and Removable Prosthodontics and Dental Material Science of the University of Zurich. The case was restored using a regular platform two-piece implant with internal connection (OsseoSpeed™ TX 4.0S, AstraTech, Dentsply). Peri-implant soft tissues had been conditioned with provisional restorations and an individualized impression coping technique was used to transfer the emergence profile to the final master cast. The master cast with the implant replica was duplicated in type IV plaster, and individual gingival masks were confectioned to simulate the peri-implant mucosal tissues. The light body polyvinyl siloxane gingival mask was replicated 60 times and changed for each test abutment.

The individualized abutments were made in zirconia by means of a CAD-CAM technique. Two different emergence profile shapes were designed using one CAD software (Atlantis abutments (Dentsply Implants, Mölndal, Sweden): CC and CV abutments (Figure 2). For both emergence profile designs, three crown-abutment margin depths were created (0 mm, 1.5 mm or 3 mm from the mucosal margin) (Figure 3). Individual lithium disilicate reinforced ceramic crowns (IPS e.max® System, Ivoclar Vivadent) were fabricated on each abutment type using a lost wax technique. The screw-access canal of the abutments was covered with a teflon band and marks were painted on the occlusal surface of crowns to indicate the canal position. These signs allowed drilling an access hole through the crown after cementation and eventually retrieving the abutment-crown complex.

Crown cementation

The cementation process was performed on a phantom head simulating the in vivo clinical procedure. The cast with the test abutment was fixated in the phantom head replicating a maxillary dental arch. The operator reclined the phantom head until it reached a horizontal position, keeping the occlusal plane perpendicular to the ground. All procedures were performed with the operator sitting behind the phantom head with the aid of a dental mirror for indirect vision of the palatal area.

After mixing the cement components (Panavia 21 [Kuraray, Osaka, Japan]) following strictly the manufacturer's recommendations, a thin uniform layer of cement was applied onto the surfaces of the crown (Brush-on application technique) (Wadhwani et al. 2012) using a brush (Ultra Brush 2.0, Microbrush Intl) mounted on a handle (Brush Tip Handle, Henry Schein). The exact amount of cement was not quantified since the cementation protocol tried to imitate a real clinical scenario. Ten crowns were cemented on each abutment modality. The cementation process was performed by one experienced clinician not involved in the cement removal procedures (DC).

Cement removal

Immediately after crown placement, a blinded investigator (MS) attempted to remove any cement excess. Foam pellets were used to remove cement excess in fluid form. Once cleaned, a glycerol-based gel (Panavia F 2.0 Oxyguard II, Kuraray) was placed over the margins, keeping constant vertical pressure on the crown for seven minutes until the cement had fully set.

A control periapical x-ray was taken using a standardized x-ray holder (Rim technique) after the clinician felt that all the cement excess was removed. If cement was observed on the control x-ray, the clinician was allowed to continue with the removal process, followed by another x-ray. This procedure was repeated until no cement was detected on the x-ray.

Subsequently, a hole was drilled through the crown to gain access to the abutment screw. The abutment with the cemented crown was removed and analyzed.

Cement excess analysis

In order to facilitate the cement excess detection, the specimens were initially stained with eosin, a red dye solution for one minute, washed and dried. Dye infiltration with eosin changed the color of the excess cement into pink/red improving the contrast and the differentiation the substrate surface and the cement.

The specimens were positioned in a custom made acrylic fixator allowing rotation of the specimen in a circular direction on the microscope table for recording two-dimensional images. Digital photos were made from 4 quadrants (buccal, distal, mesial and oral) of the abutments at x20 magnification (VH-Z 20R lens, VHX-2000D, Keyence, Osaka, Japan). The digital photos were then evaluated using a software capable of linear and area measurements (VHX-2000D Image, Keyence).

The following parameters were recorded:

- Area of cement remnants on the abutment surface (area; mm^2)
- Depth of cement remnants measured from the crown abutment margin to the abutment-implant connection (depth; mm).

After auto-calibration of the x-, y- axis to position the specimens, the digital microscopy stitched images from each abutment-crown quadrant using the depth of field composition. The lens automatically scanned the area of interest where focussed pixels were dynamically compiled using algorithms of Brenner in 5 µm intervals along the z-axis, generating a fully focused image (15 frames per second-FPS). The camera captured multiple colour images at varying brightness levels at different shutter speeds, and produced high-definition resolution images. On the image obtained from each quadrant, the circumference of the *area of cement remnants* was measured following the contours and margins of the excess cement using auto area measurement/area specified with free line tool of the software. Finally, the sum of data from 4 quadrants was considered as total amount of cement.

To detect the *depth of cement remnants*, the deepest zone of cement excess on each quadrant was selected. Starting from the crown-abutment margin a perpendicular line was drawn to the abutment-implant connection. This distance (mm) between the deepest points of cement zone apically and the crown-abutment margin defined the depth of cement remnant.

Statistical analysis

Descriptive statistics robust summaries (mean, standard deviation (SD), median, minimum and maximum, and interquartile range) were used for data report. Due to the small sample size and the fact that some data were not normally distributed, non-parametric Kruskal-Wallis and Mann-Whitney tests were used to investigate differences between groups. When more than two groups were compared between each other Bonferroni correction of the p value was performed.

Results

In total, 60 samples (10 samples for each group) were prepared and crowns cemented. Out of these, five samples could not be evaluated since the ceramic crowns broke during the drilling of the palatal access hole (CC1.5mm: 1, CC3mm: 1, CV1.5mm: 2, CV3mm: 1).

Cement remnants were found in almost all areas studied. These cement remnants were not detected by the operator on the control periapical x-rays. The amount (Table 1) and intrasulcular penetration depth (Table 2) of these remnants varied according to the abutment configuration.

Emergence profile: CC vs. CV

The emergence profile of the abutments influenced the amount and depth of cement remnants encountered after cement removal maneuvers.

Area of cement remnants

Concave abutments presented statistically more cement remnants than CV abutments when the entire abutment area of the epimucosal margin groups was evaluated (CC0mm: mean 2.31 mm^2 (SD 0.99) vs. CV0mm: mean 1.57 mm^2 (SD 0.55); p=0.043). These differences disappeared when the abutment area was analyzed broken down into quadrants (Table 1, Figure 4).

For the rest of margin depth configurations, the two emergence profiles did not reveal significant differences.

Depth of cement remnants

Concave profiles presented deeper cement remnants than CV profiles at the distal quadrant of the 0mm margin group (CC0mm: mean 1.32 mm (SD 1.22) vs. CV0mm: mean 0.29 mm (SD 0.58); p=0.02) and for the buccal quadrant of the 3 mm submucosal margin (CC3mm: mean 1.54 mm (SD 1.11) vs. CV3mm: mean 1.11 mm (SD 0.36); p=0.00). For the remaining margin configurations and areas studied no significant differences were observed (Table 2, Figure 5).

Crown-abutment margin location: 0 mm vs. 1.5 mm vs. 3 mm

Both the amount and depth of cement remnants were significantly influenced by the location of the crown-abutment margin (Figure 6 and 7).

Area of cement remnants

A statistically significant increase of remnants was detected when the crown-abutment margin was located more submucosally for every abutment studied (0mm vs. 1.5mm: $p<0.000$, 0mm vs 3mm: $p<0.000$, 1.5mm vs. 3mm: $p<0.000$).

Depth of cement remnants

When the depth of cement remnants was evaluated, the absolute values obtained for the epimucosal level were greater than those obtained when the margin was positioned 1.5 mm submucosally (for details see tables 2 and 3). The deepest cement remnants were found for the 3 mm submucosal margin configuration (Buccal quadrant: mean 1.33 mm (SD 0.55), Mesial quadrant: mean 2.69 mm (SD 1.11), Oral quadrant: mean 1.62 mm (SD 1.01), Distal quadrant: mean 2.46 mm (SD 1.02). They reached statistical significance for every quadrant except for the palatal area when compared with the other 2 margin depths (Table 3).

Abutment area: Buccal, Mesial, Oral, Distal

Area of cement remnants

Cement rests were unevenly distributed around the abutment surfaces (Table 1, Figure 6). The buccal quadrant demonstrated constantly the least amount of remnants at all margin level locations. This difference, however, only reached statistical significance at the epimucosal margin configuration and compared with the oral quadrant of the 1.5 mm submucosal margin (Table 4). At the 1.5 mm margin configuration, the oral quadrant was the area that presented the greatest quantity of cement remnants. For the 3 mm submucosal group, no significant differences among quadrants were found, but the interdental areas were those with the greatest amount of cement rests.

Depth of cement remnants

When the depth of cement rests was analyzed according to abutment area, no significant differences in location were found for the epimucosal and 1.5 mm submucosal groups, whereas the interdental areas of the 3 mm submucosal abutment margin design presented statistically significantly deeper remnants than the buccal and oral regions (Table 5).

Discussion

The present in vitro investigation revealed that i) implant abutments with a concave submucosal design result in greater amounts and deeper cement remnants than convex emergence profiles, ii) deeper crown-abutment margins entailed greater amounts of cement remnants; iii) cement remnants were more difficult to remove at oral and interdental surfaces than at the buccal aspect of abutments and, iv) periapical x-rays did not allow the clinician to identify all cement remnants present after the removal procedures.

Current clinical guidelines advice to place two-piece dental implants in the esthetic zone 3 to 4 mm apical to the prospective mucosal margin to allow for a proper prosthetic emergence profile (Buser et al. 2004; Salama et al. 1997). This idea is based on prosthodontics needs. A sufficient vertical distance is desirable to allow the abutment shape to smoothly transition from its round, narrow diameter at the implant connection to its wider, oval shape at the marginal area. The so-called emergence profile, representing the intramucosal part of the reconstruction, is usually created using a provisional reconstruction (Alani & Corson 2011; Buskin & Salinas 1998; Cho et al. 2007; Priest 2005; Wittneben et al. 2016). During this process, the narrow, concave emergence profile of the provisional reconstruction is transformed into a wider more convex profile through the addition of flowable composite. Two to three appointments are necessary to obtain a fully convex profile. These additional steps are cost-intensive and technically sensitive. Demands from patients and clinicians, therefore led to the use of a concave intramucosal profile of provisional and final reconstructions, avoiding or at least reducing additional steps of adding composite. Clinically, concerns were raised that with a concave emergence profile, proper control of excess cement could be difficult or even jeopardized. These speculations and concerns were in part supported by the outcomes of the present study. Concave abutments impeded the removal of cement remnants more than convex abutments. Differences between profiles, however, were only present for the abutments with an epimucosal margin position. For this abutment design, the sub-marginal abutment profile was longer and more pronounced than for the other two submucosal margin positions. This fact could have allowed more cement to be displaced into the profile concavity and hindered its subsequent removal. Statistical differences between abutment configurations may have disappeared for shorter profiles since the creation of marked concavities or convexities was more difficult to obtain with small vertical distances (= distance between implant and mucosal margin). Other factors such as the increased pressure generated by the convex profiles on the gingival masks could also have contributed to the accumulation of fewer amounts of cement excesses.

Yet, these results should be interpreted with caution. Even though the phantom, materials, cementation and subsequent cement excess removal procedures were kept as close as possible to clinical reality, the artificial nature of the study setup might limit, at least in part, a clinical translation of the outcomes. Albeit individual gingival masks that imitated the peri-implant soft tissue pressure were used for every cementation procedure, the study setup cannot fully replicate the complex nature of the peri-implant sulcus and its interaction with the submucosal anatomy of a specific abutment configuration. Therefore, further clinical research is needed needed to confirm or contradict the obtained results.

Based on preclinical and clinical research (Linkevicius et al. 2013a; Linkevicius et al. 2013b; Linkevicius et al. 2011; Wasiluk et al. 2016), deeper implant abutment margins are associated with greater amounts of submucosal cement remnants. The present investigation corroborates that statement, since the amount of rests increased significantly as the margin moved from an epimucosal position, to a 1.5 mm, and finally to a 3 mm submucosal position.

Unlike most previous studies (Agar et al. 1997; Linkevicius et al. 2013b; Linkevicius et al. 2011; Singer & Serfaty 1996; Wilson 2009), the present investigation analyzed the quantity and depth of the remnants at different regions of the crown-abutment complex. These findings are clinically relevant since they uncover the problematical areas where cement remains after careful removal procedures. This is even more important since peri-apical x-rays usually obtained to reveal cement excess fail to be a reliable instrument for buccal and oral region (Wilson 2009). Recently, a clinical investigation has addressed the location of cement rests around implant abutments demonstrating that the majority of residues where located interdentally and that the buccal region presented the lowest incidence of cement existence (Wasiluk et al. 2016) . In the present study, the buccal abutment surface was constantly the location where less remnants were found, possibly due to the direct visual access and instrumentation comfort experienced in this area. When the depth of remnants was studied, the mesial and distal quadrants presented the deepest residues. Taking into consideration that depth was measured from the crown-abutment margin, more than 2.5 mm mean depth values found at the interdental regions of the 3 mm submucosal margin position group imply that cement remnants remained over 5.5 mm submucosally. This area is impossible to reach clinically and therefore, this crown-abutment margin location should always be avoided.

According to the results of the present study and those of previous investigations (Agar et al. 1997; Gapski et al. 2008; Linkevicius et al. 2013a; Linkevicius et al. 2013b; Linkevicius et al. 2011; Pauletto et al. 1999; Sailer et al. 2012; Wasiluk et al. 2016; Wilson 2009), the crown abutment margin should be located as coronally as possible to minimize the amount of cement remnants. Clinically, this ideal margin location is frequently not feasible the crown-abutment interface should, for esthetic purposes, be hidden. Given the results obtained in the present investigation, it cannot be recommended to place the abutment margin deeper than 1.5 mm buccally or epimucosally in the interdental and oral regions based on in vitro data. Clinically, even at 1mm below the crown margin, cement remnants were found (Linkevicius et al. 2011; Wasiluk et al. 2016).

Conclusions

Concave emergence profile abutments and deeper crown-abutment margin positions increased the risk of cement remnants on the abutment surface. Concave abutments presented more cement remnants than convex abutments for the epimucosal margin groups. Significantly more remnants were detected as the crown-abutment margin was located more submucosally for every abutment studied.

Acknowledgments

This study was supported by the Clinic of Fixed and Removable Prosthodontics and Dental Material Science, Center of Dental Medicine, University of Zurich, Switzerland.

The implants and the abutments were kindly provided by Dentsply Sirona Implants, Mölndal, Sweden.

Figure legends:

Figure 1. Sample distribution of abutment designs.

Figure 2. Digital designs of the two emergence profiles within the anonymous clinical case. A lateral view concave; B. buccal view concave; C. lateral view convex; D. buccal view convex

Figure 3. Anonymous clinical case. Cast mounted in phantom head. A. Abutment with shoulder height at the level of the margo mucosae. B. Cementation of crown. C. After removal of cement excess.

Figure 4. Overall area of cement remnants (mm^2) according to emergence profile and crown-abutment margin position configurations.

Figure 5. Depth of cement remnants (mm) for each abutment quadrant according to emergence profile and crown-abutment margin position configurations

Figure 6. Area of cement remnants (mm^2) for each abutment quadrant according to crown-abutment margin position.

Figure 7. Depth of cement remnants (mm) for each abutment quadrant according to crown-abutment margin position.

Tables:

Table 1.

Area (mm^2) of cement remnants. Descriptive (mean, standard deviations (SD), median, minimum (Min) and maximum (Max), interquartile range (IQR)) and inferential statistics (Mann-Whitney test) are presented for individual quadrants (Buccal, Mesial, Oral, Distal) and for the entire abutment area (TOTAL). The p values provided for a specific margin depth and quadrant are the result of the statistical comparison between both emergence profiles for the same depth and quadrant.

Emergence profile	Margin depth	Quadrant	N	Mean	SD	**Median**	Min	Max	IQR	p
Concave	0 mm	Buccal	10	0.32	0.39	**0.23**	0.08	1.42	0.18	0.85
		Mesial	10	0.72	0.57	**0.61**	0	1.67	0.87	0.62
		Oral	10	0.64	0.39	**0.61**	0.12	1.34	0.66	0.15
		Distal	10	0.62	0.28	**0.67**	0.1	0.96	0.38	0.08
		TOTAL	10	2.31	0.99	**2.27**	0.88	4.23	1.32	0.04
	1.5 mm	Buccal	9	0,89	0.38	**0.78**	0.36	1.42	0.72	0.17
		Mesial	9	1.19	0.41	**1.27**	0.44	1.7	0.62	0.53
		Oral	9	1.78	0.74	**1.79**	0.94	3.22	1.23	0.02
		Distal	9	0.98	0.34	**0.93**	0.56	1.44	0.67	0.90
		TOTAL	9	4.84	1.11	**4.84**	3.32	6.32	2.24	0.28
	3 mm	Buccal	9	1.49	0.97	**1.33**	0.33	3.46	1.31	0.07
		Mesial	9	2.74	1.27	**2.85**	0.87	4.4	2.4	0.81
		Oral	9	1.86	1.41	**1.28**	0.63	4.99	1.66	0.35
		Distal	9	2.17	0.97	**2.31**	0.85	3.68	1.72	0.54
		TOTAL	9	8.02	2.48	**7.7**	4.99	12.41	3.97	0.28
Convex	0 mm	Buccal	10	0.23	0.14	**0.23**	0.05	0.42	0.28	0.85
		Mesial	10	0.53	0.29	**0.5**	0.15	0.96	0.57	0.62
		Oral	10	0.42	0.27	**0.31**	0.2	1.1	0.32	0.15
		Distal	10	0.39	0.31	**0.23**	0.14	1.1	0.42	0.08
		TOTAL	10	1.57	0.55	**1.66**	0.8	2.51	0.69	0.04
	1.5 mm	Buccal	8	0.86	0.94	**0.34**	0.17	2.41	1.73	0.17
		Mesial	8	1.26	0.83	**1**	0.31	2.77	1.29	0.53
		Oral	8	1.19	0.96	**0.73**	0.39	3.15	1.28	0.02
		Distal	8	1.17	0.59	**0.97**	0.53	2.28	0.88	0.90
		TOTAL	8	4.48	1.98	**4**	1.92	8.05	2.98	0.28
	3 mm	Buccal	9	2.21	0.86	**2.35**	0.8	3.76	1.19	0.07
		Mesial	9	2.63	1.06	**2.77**	1.09	4.12	1.94	0.81
		Oral	9	2.07	0.85	**2.03**	0.62	3.23	1.42	0.35
		Distal	9	2.31	0.65	**2.54**	1.38	3.01	1.28	0.54
		TOTAL	9	9.23	2.53	**10.03**	3.94	11.52	3.84	0.28

Table 2.

Depth (mm) of cement remnants measured from the crown-abutment margin. Descriptive (mean, standard deviations (SD), median, minimum (Min) and maximum (Max), interquartile range (IQR)) and inferential statistics (Mann-Whitney test) are presented for individual quadrants. The p values provided for a specific margin depth and quadrant are the result of the statistical comparison between both emergence profiles for the same depth and quadrant.

Emergence profile	Margin depth	Quadrant	N	Mean	SD	**Median**	Min	Max	IQR	p
Concave	0 mm	Buccal	10	0.82	0.52	**0.81**	0.19	1.6	1.1	0.41
		Mesial	10	0.95	1.18	**0.36**	0	3	2.25	0.52
		Oral	10	0.93	1.25	**0.31**	0	3.44	1.8	0.45
		Distal	10	1.32	1.22	**1.31**	0	3.47	2.05	0.02
	1.5 mm	Buccal	9	0.07	0.11	**0**	0	0.33	0.14	0.78
		Mesial	9	0.3	0.55	**0.09**	0	1.7	0.37	0.12
		Oral	9	0.49	0.83	**0**	0	2.33	0.98	0.12
		Distal	9	0.27	0.61	**0.09**	0	1.91	0.15	0.83
	3 mm	Buccal	9	1.54	0.41	**1.74**	0	2.36	0.32	0.00
		Mesial	9	2.88	1.1	**3.2**	0	3.65	0.39	0.13
		Oral	9	1.47	1.22	**2.34**	0	2.64	2.48	0.51
		Distal	9	2.37	1.36	**3.04**	9	3.4	1.96	0.25
Convex	0 mm	Buccal	10	0.66	0.6	**0.6**	0	1.85	0.8	0.41
		Mesial	10	0.95	1.07	**0.55**	0	2.95	1.08	0.52
		Oral	10	1.23	1.16	**0.67**	0.19	2.92	1.23	0.45
		Distal	10	0.29	0.58	**0**	0	1.84	0.4	0.02
	1.5 mm	Buccal	8	0.45	0.68	**0**	0	1.7	1.12	0.78
		Mesial	8	0.76	0.76	**0.52**	0	2.06	1.38	0.12
		Oral	8	0.79	1.2	**0.36**	0	3.66	0.74	0.12
		Distal	8	0.76	1.18	**0.23**	0	3.25	1.49	0.83
	3 mm	Buccal	9	1.11	0.36	**1.19**	0.17	1.33	0.18	0.00
		Mesial	9	2.5	1.15	**3.03**	0	3.28	1.27	0.13
		Oral	9	1.77	0.79	**2.12**	0	2.25	0.73	0.51
		Distal	9	2.56	0.55	**2.77**	1.24	3	0.54	0.25

Table 3.

Statistical differences between depth of cement remnants among the different crown-abutment margin positions (Mann-Whitney test).

Comparison	Groups		N	p
Crown-abutment margin comparison	0 mm vs. 1.5 mm	Buccal	39	0.000
		Mesial	38	0.133
		Oral	39	0.089
		Distal	39	0.396
	1.5 mm vs. 3 mm	Buccal	37	0.000
		Mesial	36	0.000
		Oral	37	0.012
		Distal	37	0.000
	0 mm vs. 3 mm	Buccal	38	0.006
		Mesial	38	0.000
		Oral	38	0.361
		Distal	38	0.000

Table 4.

Statistical differences between areas of cement remnants among quadrants for each margin position.

Margin depth	Quadrant comparison	N	p
0mm	Buccal vs. Mesial	40	0.001
	Buccal vs. Oral	40	0.003
	Buccal vs. Distal	40	0.009
	Oral vs. Distal	40	0.718
	Oral vs. Medial	40	0.62
	Mesial vs. Distal	40	0.512
1.5mm	Buccal vs. Mesial	37	0.017
	Buccal vs. Oral	38	0.01
	Buccal vs. Distal	38	0.075
	Oral vs. Distal	38	0.212
	Oral vs. Medial	37	0.499
	Mesial vs. Distal	37	0.374
3mm	Buccal vs. Mesial	35	0.022
	Buccal vs. Oral	36	0.96
	Buccal vs. Distal	36	0.192
	Oral vs. Distal	36	0.252
	Oral vs. Medial	35	0.027
	Mesial vs. Distal	35	0.143

Table 5.

Statistical differences between depth of cement remnants (mm) among quadrants for each margin position.

Margin depth	Quadrant comparison	N	p
0 mm	Buccal vs. Mesial	40	0.881
	Buccal vs. Oral	40	0.793
	Buccal vs. Distal	40	0.321
	Oral vs. Distal	40	0.242
	Oral vs. Mesial	40	0.862
	Mesial vs. Distal	40	0.301
1.5 mm	Buccal vs. Mesial	37	0.423
	Buccal vs. Oral	38	0.101
	Buccal vs. Distal	38	0.232
	Oral vs. Distal	38	0.583
	Oral vs. Mesial	37	0.753
	Mesial vs. Distal	37	0.443
3 mm	Buccal vs. Mesial	36	0.000
	Buccal vs. Oral	36	0.090
	Buccal vs. Distal	36	0.000
	Oral vs. Distal	36	0.001
	Oral vs. Mesial	36	0.000
	Mesial vs. Distal	36	0.068

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Figures

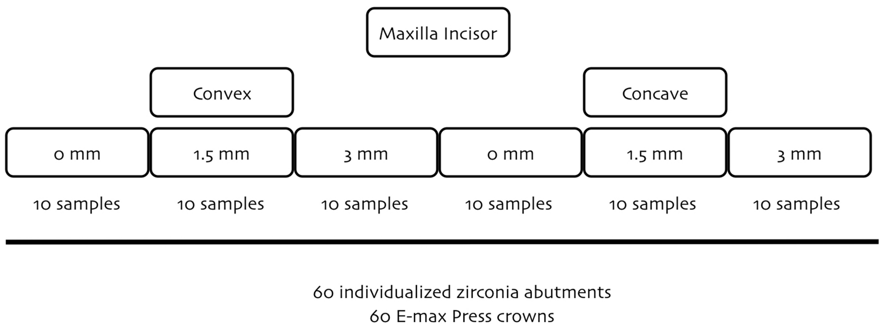

Figure 1

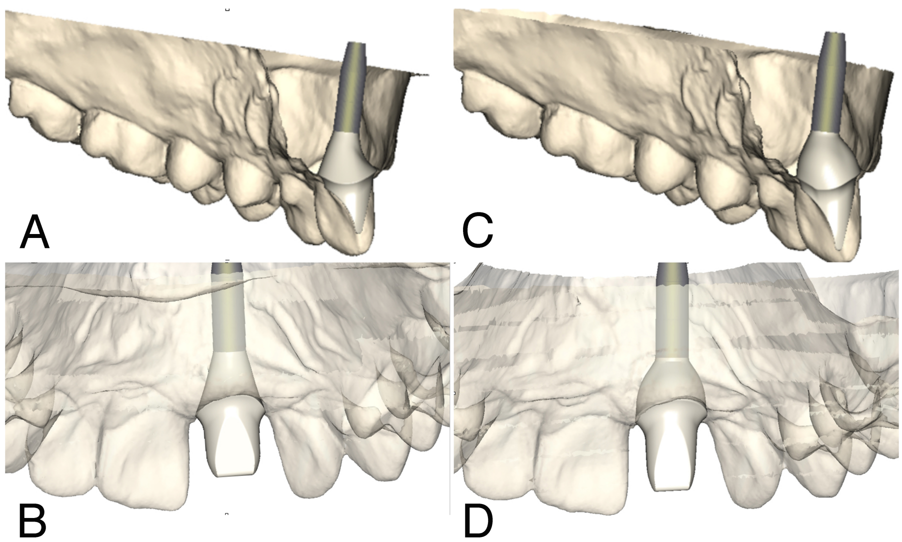

Figure 2

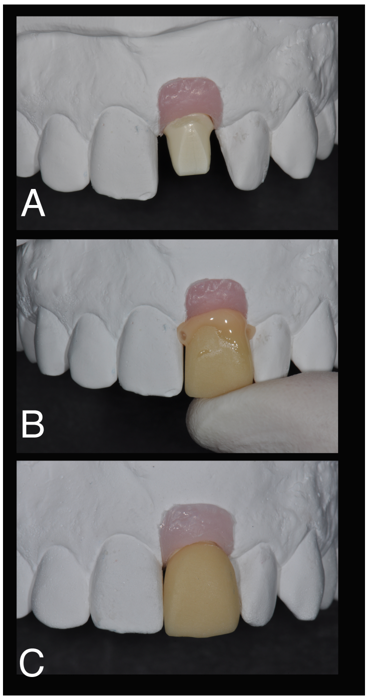

Figure 3

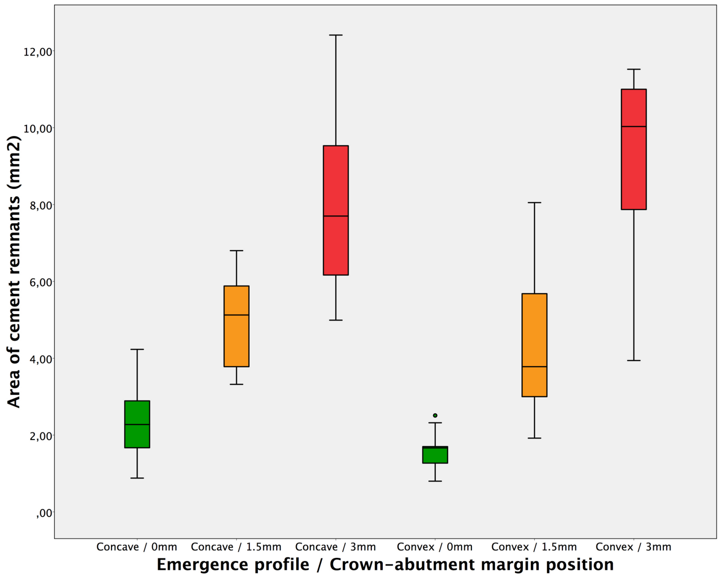

Figure 4

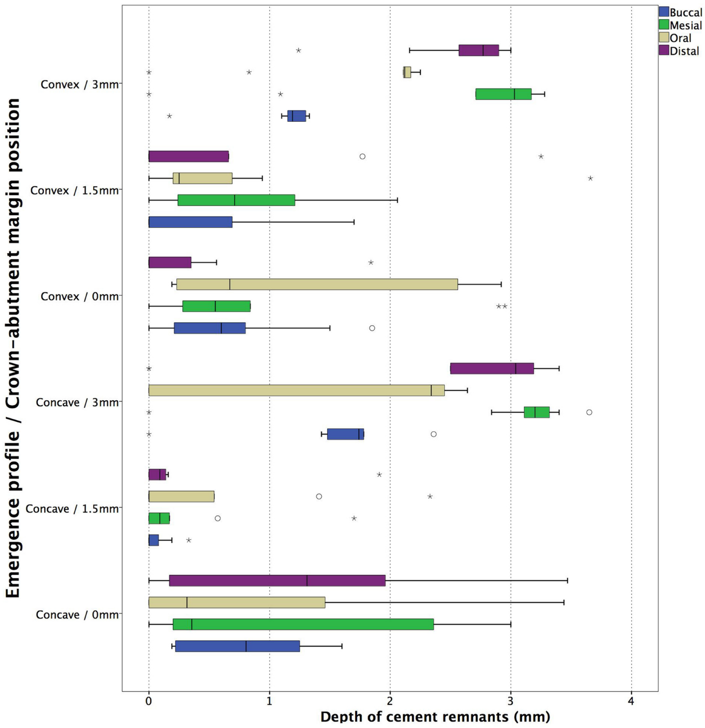

Figure 5

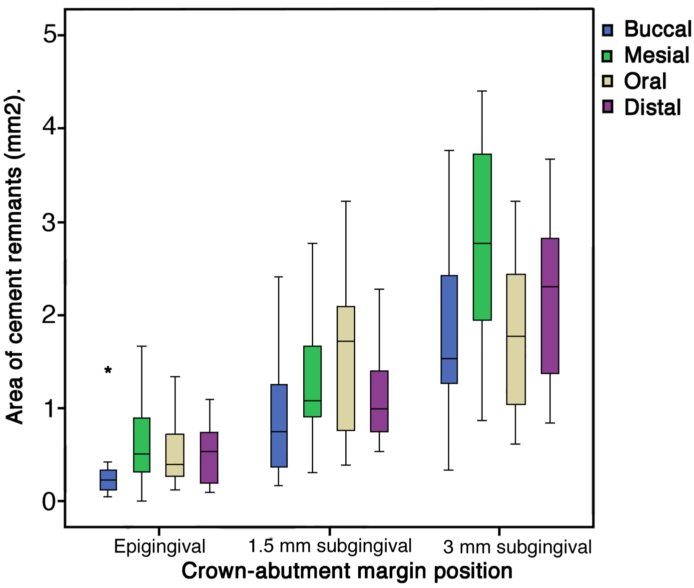

Figure 6